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Approach to Effect of Obstacle on Pedestrian Evacuation with a Small-Grid Lattice Gas Model

Yan-Fang Wei[a,b*], Wei Shi[a,c], Tao Song[a]

[a]Shanghai Institute of Applied Mathematics and Mechanics, Shanghai University,Shanghai, 200072, China
[b]College of Physical Science and Technology, Yulin Normal University, Yulin, 537000, China
[c]Department of Physics and Mathematics, Wuzhou University, Wuzhou, 543002, China

Abstract

Evacuation time taken by people to escape out of a room with obstacle is investigated by using a small-grid lattice gas model with different maximum velocities. The relationship between the evacuation time and the obstacle size and distance to the exit is investigated. The simulation results show that the evacuation time decreases when the obstacle is set appropriately under various densities. Additionally, the numbers of pedestrians escaping out of the room with and without obstacle at each time step are also compared and discussed in detail.

Keywords: Obstacle; Evacuation time; Small grid; Lattice gas model

1. Introduction

Recently, pedestrian dynamics has attracted increasing attention of researchers because of its complex characteristics and wide applications in reality [1-11]. The lattice gas model [2] is one of main approaches to study pedestrian dynamics and has been extensively studied and applied. The human subconscious behavior and different maximum velocities were introduced, in the study of pedestrian counter flow by Kuang [3]. In Ref. [4], a classroom evacuation was examined and it was found that the optimum position of a double-exit door is at the back of the room. The effects of pillar-like and panel-like obstacles on evacuation time with the social force model were investigated in [5]. Matsui et al. [6] studied the channel

* Corresponding author. Tel:+86-15921815109
E-mail address: yanfangwei2007@hotmail.com

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flow of mobile objects through obstacles using an extended lattice gas model by considering translational particles and turning particles. However, in the traditional lattice gas models, coarse grid partition was used, and as a result, such collective phenomena as the arching and clogging behavior, could not be reproduced well. Finer lattice, which enables one to represent detailed movement of pedestrians, was introduced in Ref. [7]. Xu et al. studied the discretization effect in a multi-grid egress model [8]. Classroom and hall evacuation process were explored by Weng and Zhang, respectively [9,10]. But they have not considered the obstacle effect in pedestrian evacuation process. On the basis of the small-grid lattice gas model proposed by Weng [9], we study the effect of the obstacle size and distance to the exit on evacuation time when pedestrians with different speeds escape from a one-door room via numerical simulation.

2. Model

In this model, the usual occupied space of a walker, namely a square of 40×40 cm^2, is divided into smaller grids of 10×10 cm^2 and a walker can move through one or more small grids (1/4 coarse grids) at a time step. Figure 1 is the sketch of the coarse grid model and the small-grid model. In Fig. 1, a circle denotes a walker. For simplicity, we assume that all of the grids occupied by a pedestrian are prevented from overlapping with others. The possible configurations of a pedestrian and the corresponding transition probabilities are the same as those in the lattice gas model in Ref. [11]. Some pedestrians attempt to leave from a one-door square room with an obstacle. There are two kinds of pedestrians: faster ones with the maximum velocity of 6 small grids at a time step and slower ones with the velocity of 3 small grids at a time step. We assume that a walker spends the same walking time of 0.4 s at a time step.

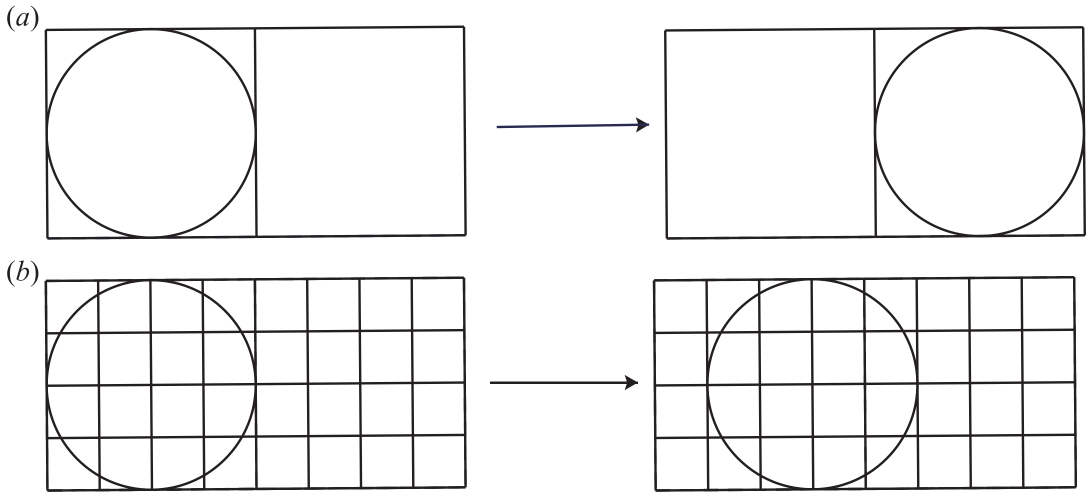

Fig. 1 Sketch of the coarse grid model and the small-grid model. (a) The coarse grid model. The cell grid is 40×40 cm^2. A walker moves a coarse grid at a time step, with corresponding velocity of 0.4 m/step. (b) The small-grid model. A walker moves a small grid (1/4 coarse grid) at a time step, with corresponding velocity of 0.1 m/step.

And the desired velocity of 0.75 and 1.5 m/s correspond to 3 and 6 small grids at a time step, respectively. The room size is assumed to be 4×4 m^2 and the exit door width is 1.2 m. Sequential update is chosen. Initially, pedestrians are distributed randomly. At each time step, walkers are numbered randomly from 1 to N, where N is the total number of walkers in the room, and then each walker is updated once in the sequential order from 1 to N. After all the walkers are updated, updating for one time step is completed. If the walkers go out of the system, they will be removed from the system. The above procedure is repeated till all the persons have left from the room.

3. Simulation and results

We present the simulation results as follows, in which the drift is set as 0.5. We use R to denote the fraction of faster pedestrians. As R is smaller than (greater than) 0.5, the quantity of the faster pedestrians is smaller than (greater than) that of slower pedestrians. In the direction parallel to the door, the size of the obstacle is named as the width of the obstacle and the size in the direction perpendicular to the door is named as the length. The centers of the obstacle and the door are in alignment. In our simulation, the size of the obstacle is set as one or several small grids. The process of evacuation is simulated 100 times by computer.

Table 1 is the evacuation time under different densities without obstacle given by numerical simulation

Table 1. Evacuation time under different densities without obstacle.

density	R=0.4
0.3	21.640 s
0.5	29.788 s
0.8	43.736 s

Figure 2 shows the relationship between the evacuation time and the distance between the obstacle and door as R is 0.4. When the density is 0.3, there seems to be no obvious regular pattern between the evacuation time and the distance of obstacle to the exit when the size of the obstacle is fixed. In Fig. 2(a), when the width and length of obstacle are three and four small grids, the evacuation time drop abruptly before the distance reaches 1.2 m. When the distance is greater than 1.2 m, the evacuation time is increased. When the distance is greater than 2 m, the evacuation time decreases and reaches the minimum of 20.688 s at the distance of 2.8 m. Then the evacuation time rises again. When the occupation probability increases to 0.5 and 0.8, the evacuation time is shortened with the raise of the distance until the distance is 1.6 m. When the distance is greater than 1.6 m, the evacuation time fluctuates. And the evacuation time is almost the same for different sizes of obstacles when the distance of obstacle to the exit is more than 1.6 m. When the width and length of barrier are three and two small grids, the minimum evacuation time of 28.84 s is obtained at the distance of 2.4 m under the density of 0.5. When the density is 0.8, the evacuation time reaches the minimum of 41.86 s while the obstacle size is 3×6 small grids at the distance of 1.6 m. From Fig.2 it is found that the obstacle, which is set appropriately under different densities, reduces the conflicts among pedestrians when pedestrians escape out of the room and then shortens the evacuation time about 1 s compared with that without obstacle in table 1.

Figure 3 is the plot of the number of pedestrians escaping from the room at each time step under different densities. Figure 3 shows the comparison of the number of pedestrians without and with obstacle as R is 0.4. It can be seen that the number of pedestrians in the case with obstacle is greater than that in the case without obstacle at the beginning. Then the number of walkers escaping out of the room with obstacle fluctuates around that in the case without obstacle. After a while, the numbers of pedestrians in two situations are almost the same. At the beginning of the evacuation process, the conflicts between the pedestrians far away from the door and those near the exit is reduced because of the obstacle and that make the walkers near the door escape out of the room quickly. As time goes by, more and more people who are relatively near the door move toward the exit, and the positive effect of obstacle is weakened and sometimes the movement of walker is hindered by obstacle. When most of the pedestrians in the room have escaped out of the exit, the effect of the obstacle vanishes and the numbers of pedestrian escaping out of the room with and without the obstacle are almost the same.

4. Conclusions

In this paper, the evacuation time of pedestrians escaping out of a room with obstacle has been investigated via a small-grid lattice gas model with different maximum velocities. It is found that the obstacle in some way contributes to optimize the evacuation process by reducing the conflicts among pedestrians. The obstacle with the size of 3×4 small grids and the distance of 2.8 m between the obstacle

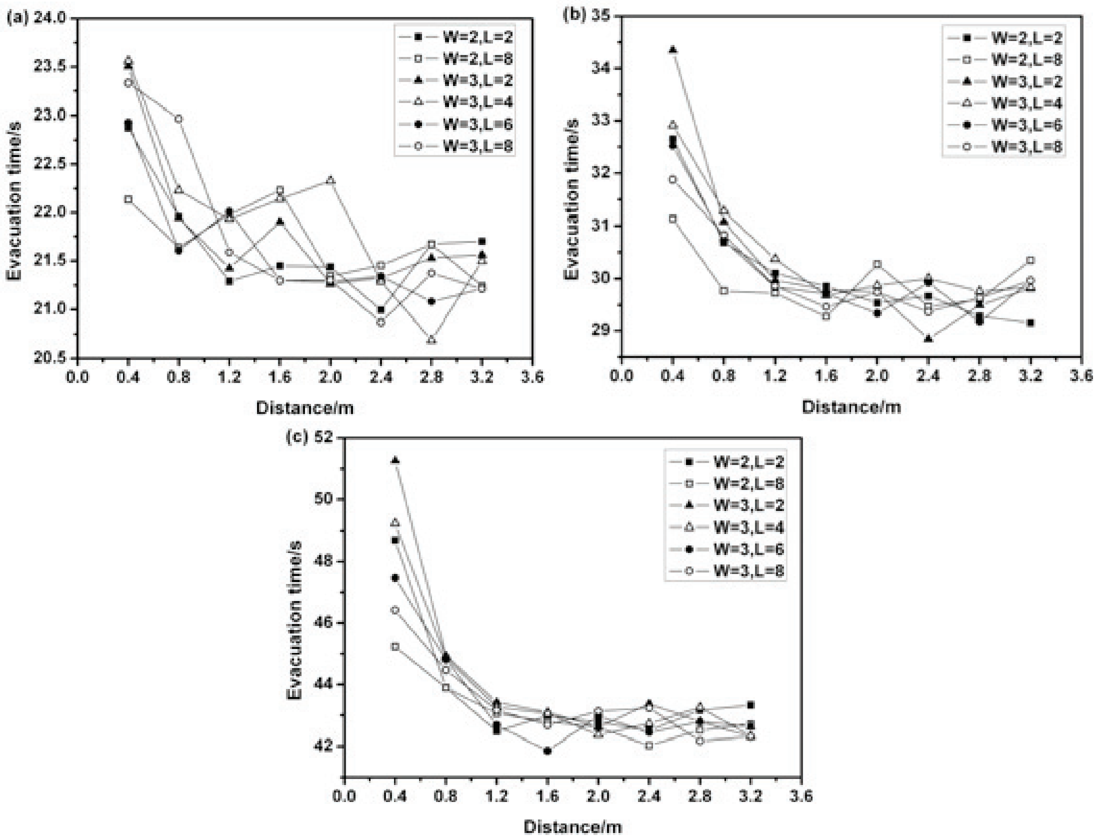

Fig.2 Curve of evacuation time against distance of obstacle to the door for density (a) 0.3, (b) 0.5 and (c) 0.8. Here R is 0.4, and W and L denote the width and length of the obstacle, respectively.

and the exit can improve the evacuation time with the density of 0.3 when the faster pedestrians are less than the slower pedestrians. When the density is 0.5, the minimum evacuation time is gained when the obstacle size is 3×2 small grids and the distance to the door is 2.4 m. In dense pedestrians flow, we obtained the least evacuation time when the distance of obstacle to the exit is 1.6 m and the width and length of barrier are three and six small grids. It is showed that the obstacle, which is set appropriately under different densities, can reduce the evacuation time about 1 s compared with the case without obstacle.

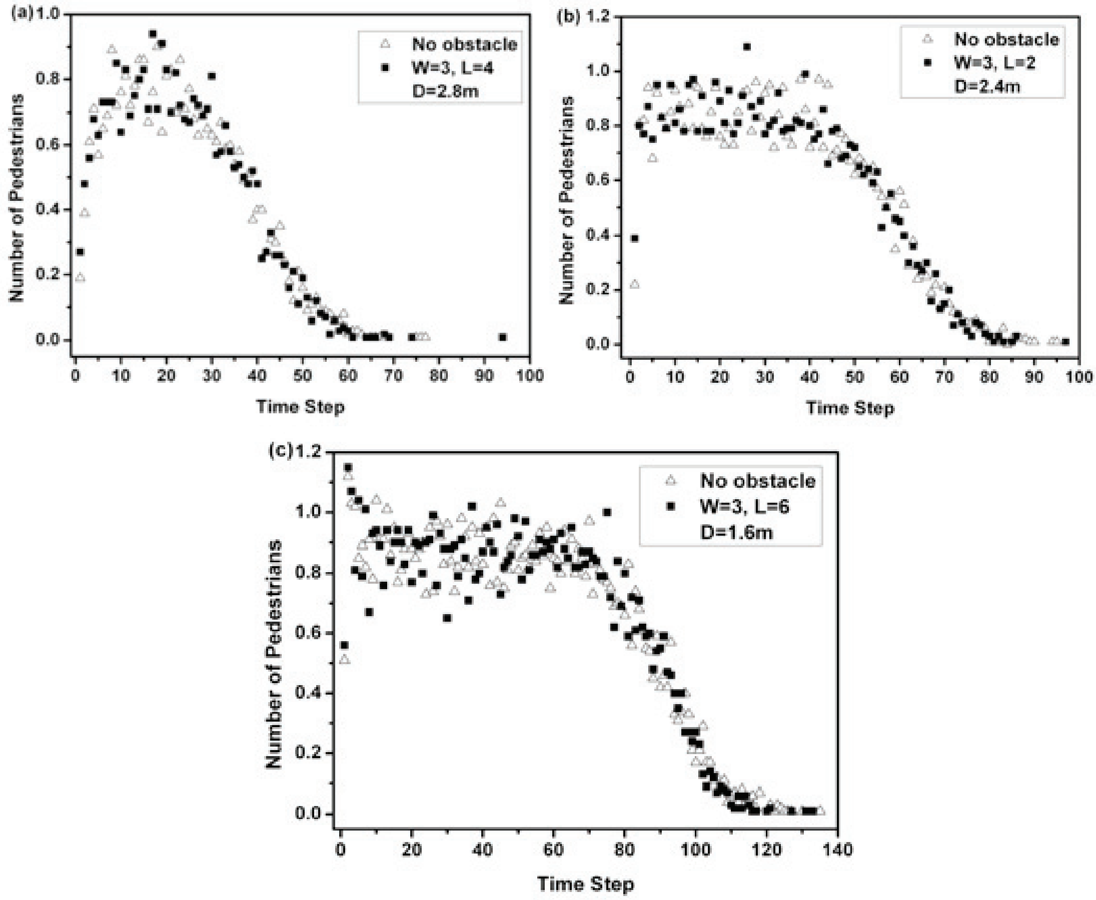

Fig. 3 Number of pedestrians against time step for density (a) 0.3, (b) 0.5 and (c) 0.8. Here R is 0.4, and W, L and D denote the width and length of the obstacle and the distance of obstacle to the exit, respectively.

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